

Managing the uncertainty in soil mapping and land evaluation in areas of high pedodiversity. Methods and strategies applied in the province of Siena (Central Italy)

Costantini E.A.C., Barbetti R., Righini G.

in

Zdruli P. (ed.), Steduto P. (ed.), Kapur S. (ed.).
7. International meeting on Soils with Mediterranean Type of Climate (selected papers)

Bari : CIHEAM

Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 50

2002

pages 45-56

Article available on line / Article disponible en ligne à l'adresse :

<http://om.ciheam.org/article.php?IDPDF=4002019>

To cite this article / Pour citer cet article

Costantini E.A.C., Barbetti R., Righini G. **Managing the uncertainty in soil mapping and land evaluation in areas of high pedodiversity. Methods and strategies applied in the province of Siena (Central Italy)**. In : Zdruli P. (ed.), Steduto P. (ed.), Kapur S. (ed.). *7. International meeting on Soils with Mediterranean Type of Climate (selected papers)*. Bari : CIHEAM, 2002. p. 45-56 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 50)



<http://www.ciheam.org/>
<http://om.ciheam.org/>

MANAGING THE UNCERTAINTY IN SOIL MAPPING AND LAND EVALUATION IN AREAS OF HIGH PEDODIVERSITY. METHODS AND STRATEGIES APPLIED IN THE PROVINCE OF SIENA (CENTRAL ITALY)

EDOARDO A.C. COSTANTINI, ROBERTO BARBETTI, AND GAIA RIGHINI

*Istituto Sperimentale per lo Studio e la Difesa del Suolo
p.za M.D'Azeglio 30, 50121 Firenze, e-mail: costantini@issds.it*

Introduction

Soil mapping and land evaluation frequently lack a convincing explication of the uncertainty of the information provided. As a rule, the main confidence index is the density of observations, although scale of the aerial photos utilised, topographic maps etc., can furnish further elements, useful in judging the quality of the work.

The density of the observations follows a set of variables: cartographic scale, soil distribution complexity, site accessibility, kind of remote sensing images, financial budget, thematic maps and information technology available, that widely varies from survey to survey.

National and international organisations have proposed some guidelines in relation to the scale of mapping (FAO, 1979; Soil Survey Division Staff, 1993), however, the same density of observations can be used in different ways, i.e. to improve knowledge about variability and representativeness of soil typologies, improve precision of the limits, or to quantify inclusions inside polygons and map units.

The uncertainty about soil geography can be expressed as a percentage of inclusions inside polygons, that in fact are soils that have different typology and/or suitability (pedological “purity” and suitability “purity”). Otherwise, it can be made implicit in the name of the soil map unit, i.e. “complex”, “association”, “undifferentiated group”, and “unassociated group” (Van Wambeke and Forbes, 1986).

Besides “purity”, two other indices can be used to define the quality of the information. “Confidence” of the suitability evaluation and “reliability” of the so-called “soil survey paradigm” (Hudson, 1992), which is the relationship linking the kind of landscape to the type of soil.

The confidence index expresses how reliable is the estimation made about the soil behaviour for a certain purpose in a specific place or for a specific polygon. The reliability index that tells us how consistent is the generalisation of the relationship found between a type of soil and a specific landscape to all the landscapes with similar characteristics (Costantini and Sulli, 2000).

Soil mapping in the Mediterranean region is particularly prone to uncertainty, because of its high pedodiversity (Ibañez *et al.*, 1998). The variability of climate and lithology in a tectonically active area, which was only partially influenced by glaciers during the Quaternary, and the millennial human land exploitation and density, lead to a particularly

high soil variability even in relatively small areas. For this reason, soil-mapping units are frequently complex and impure.

The level of complexity and uncertainty of soil information inside mapping units increases with the decreasing of the scale of the map, and consequently lower the confidence of interpretations. On the other hand, maps at the semi-detailed and reconnaissance scales are the most requested by stakeholders and policy makers when addressing territorial policies (Costantini *et al.*, 1999).

The need for soil scientists and land evaluators to interpret the uncertainty of the information provided make it explicit and easy to understand, has the practical relevance of informing users about the limitations of the map, and in the meantime highlighting the areas where more detailed investigations are needed.

This study was performed using several criteria and methodologies. They included the algorithms commonly used in ecology, the Shannon's and the *evenness indices*, as well as the indicator kriging and some statistic tests applied in a non parametric way. They were used to show the purity, confidence and reliability of maps of soil and land suitability for olive tree cultivation.

Materials and Methods

The Administration of the Province of Siena (Central Italy) financed an olive tree zoning project. A detailed explanation of the methodology used in the soil survey and land evaluation was reported by Costantini and Sulli (2000). It provided the background for the creation of soil typological units and subunits of the database. The aim was to allocate each soil observation on the basis of its classification, landscape characteristics and management problems.

Soil typological subunits were the basic units for the suitability evaluation. The soil geography was described at the 1:100,000 scale following the Land System methodology (Toscana. Dip. Agricoltura e Foreste, 1992). The main components of the methodology were land systems, land units and land elements.

Land units were geographical objects (polygons) recognised and delineated by photointerpretation (aerial photos at 1:33,000 scale), having an hydrological pattern, a range of lithology (1:100,000 geological map overlaid) and geomorphology, and a set of characteristic arrangement of land elements.

Land elements were the smallest components, which could be recognised by photointerpretation of a characteristic lithology, landform and land use pattern, and could be described and codified, but not delineated on a 1:100,000 map. Besides identification, their approximate proportion inside each delineated polygon was also recorded. Land systems grouped land units together, on a physiographic and geological basis.

The entire Province of Siena was described with the Land System approach, and each soil profile stored was referred to a land element typology. During the field survey, the soil's percentage distribution in each land element was recorded in the field, and then in the

computerised database. Similar land elements formed land element typologies and each land element typology had a set of soil typological subunits.

To sum up, every map polygon belonged to one land unit and was made up of one or more land elements. Consequently, every land element was made up of one or more soil typological subunits. In each soil typological subunit a set of observations (profiles, auger holes, and mini pits) useful for soil classification, landscape, management requirements and crop suitability were allocated.

As we knew the area of each polygon and the proportion of the land elements inside it, as well as the proportion of soil typological subunits forming each land element, we were able to estimate the area covered by each land element and by each soil typology.

Regarding the land evaluation methodology, each observation was singularly evaluated and attributed to a land suitability class. Four suitability classes (0 = not suitable, 1 = moderately suitable, 2 = suitable, 3 = very suitable) were assessed on the basis of the results obtained in experimental plots, where the reference olive tree variety "Moraiolo" was cultivated.

The suitability class of a soil typological subunit was the modal value of all its observations. In turn, the suitability class of a land element was the modal value of the suitability classes found in it. All information was stored in a soil information system, which was set up by means of the software Access, Arcinfo and Arcview.

To manage soil uncertainty, data were first submitted to descriptive statistics (observations by hectare, observations by soil typological unit and subunit, observations by polygon, observations by land element). Then the Shannon's index was applied to assess pedodiversity of land elements, polygons, soil typological units and subunits. The Shannon's index is well known and widely used in Ecology, but it has been also proposed in Pedology (Ibañez *et al.*, 1995):

$$H' = - \sum_{i=1}^n p_i * \ln(p_i)$$

Where H' is the (negative) entropy and p_i is the proportion of soil individual i in the area studied. p_i can be estimated by n_i/N , with n_i = the number of individuals i and N the total number of samples. In our case, p_i was the percentage of the surface area occupied by the i object.

The Evenness index is derived from the Shannon's index and can range from 0 (maximum equality) to 1 (maximum diversity):

$$E = H'/H \text{ max} = H' / \ln S$$

Where S is the numerical richness.

In order to test the confidence of the suitability map for olive tree cultivation, an independent survey of 127 auger holes was made on a grid scheme superimposed on the part of the province concerned in the evaluation (1,600 km², excluding woodlands and

urban areas). Soil suitability of each site was evaluated and the results compared with those from the land system approach.

The comparison was made considering two or four classes of agreement. The two classes were: 0 = same suitability, 1 = different suitability; the four classes were: 0 = same class of suitability; 1 = 1 class of difference between the land system approach and the independent survey; 2 = 2 classes of difference; 3 = 3 classes of difference. The kriging interpolator, which is often used in soil science and geology (Burrough, 1986), was applied to generate an estimated surface from a set of points with the attribute values coded with a class of agreement. Semivariograms were computed in order to quantify the spatial variation and to select the model that best fitted the data.

The root mean square error (RMSE) and the index of agreement (IoA) between suitability predicted through the land system approach and observed with the grid survey were calculated. The RMSE measures the difference between predicted and observed values in quadratic terms:

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^N (P_i - O_i)^2}{N}}$$

Where P_i and O_i are predicted and observed data, respectively; N the number of data.

The IoA is a standardised RMSE. It can vary from 0, total disagreement, to 1, total agreement, between predicted and observed values:

$$\mathbf{IoA} = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i'| + |O_i'|)^2}$$

Where P_i' and O_i' are the differences between each value and the mean value, for predicted and observed data, respectively.

Results and Discussions

The study area is part of the province of Siena, which is situated in Tuscany, Central Italy. Descriptive statistics confirmed the high diversity of the area, in terms of both soil typologies and landscapes (land elements) (Table 1).

Table 1. Descriptive statistics of the soil survey in the study area (3,806 km²).

	Profiles	Observations	Soil Typological Units	Soil Typological Subunits	Land Element typologies	Polygons
Number	530	1231	47	141	640	601
	Density (n/km ²)			Extension (km ²)		
Mean	7.18	3.09	80.98	26.99	5.94	6.33
Minimum			2.24	0.04	0.08	0.48
Maximum			355.65	351.46	404.6	37.92

In terms of Soil Taxonomy taxa (Soil Survey Staff, 1999), the soils found in the area belong to 6 orders, 15 suborders, 26 great groups, and 64 subgroups (Table 2).

Table 2. Soil taxa in the study area according to Soil Taxonomy (Soil Survey Staff, 1999).

Soil Taxonomy orders	Soil Taxonomy great groups	Soil Taxonomy subgroups	
Alfisols	Haploxeralf	Aquic Aquultic Lithic Lithic-mollic Typic Ultic Vertic	
	Hapludalf	Aquic Lithic Typic Udic	
	Paleudalf	Rhodic Typic	
	Paleustalf	Ultic	
	Palexeralf	Aquic Fluventic Typic Ultic	
	Rhodoxeralf	Typic	
	Andisols	Melanudand	Pachic
		Entisols	Endoaquent
	Epiaquent		Aeric
	Fluvaquent		Aquic
Udifluent	Typic		
Udorthent	Aquic Lithic Typic Vertic		
Ustipsamment	Typic		
Ustorthent	Aquic Lithic Typic Vertic		
Xerarents	Alfic Lithic		
Xerofluent	Aquic Typic		
Xeropsamment	Lithic Typic		
Xerorthent	Aquic Lithic Typic Vertic		
Inceptisols	Dystrudept		Aquic Typic
	Epiaquept		Vertic
	Haplustept	Aquic Fluventic Typic Udic	
	Haploxerept	Aquic Calcic Humic Fluventic Lithic Typic Vertic	
	Calcixerept	Typic	
Mollisols	Haploxeroll	Lithic Ruptic-lithic Typic	
Vertisols	Calcixerert	Chromic Typic	
	Haploxerert	Aquic	

The evenness index was applied to evaluate pedological diversity of land element typologies. It was calculated as proportion of the area covered by the different soil typological subunits found in each land element, weighted according to their extension (Figure 1).

Most of the 640 land element typologies resulted as having only one soil typology, although a minor part could have a remarkable diversity. The mean value of evenness was the reliability index of the soil survey paradigm. Since it this index resulted rather low (0.0063), the relationship linking landscape with soil typology was on average quite consistent.

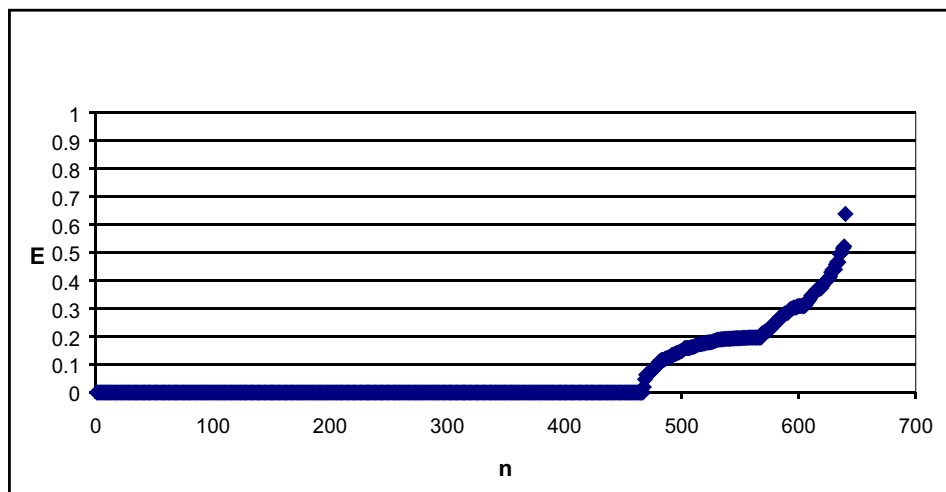


Figure 1. Reliability index: pedological diversity of land elements. pi = soil typological subunits (STS) / land element (LE) (km^2/km^2); E mean = 0.063.

When we considered the different kinds of landscape, i.e. land elements, found in each of the 141 soil typological subunits, the mean value of the evenness index rose up to 0.132 (Figure 2). The graph below shows that in most cases soil typologies were not homogeneous, but the low evenness index demonstrates that the inclusions were limited in number and in extension.

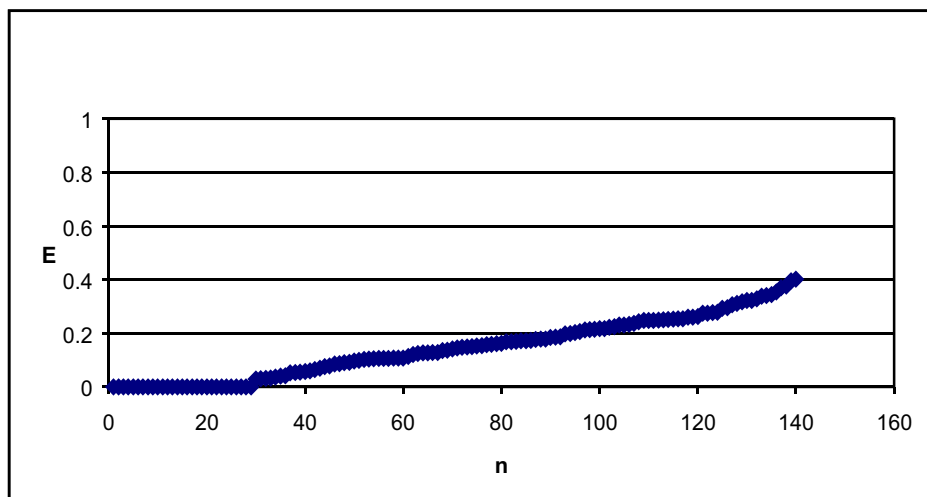


Figure 2. Geographical diversity of soils. pi = LE/STS (km^2/km^2); E mean = 0.132.

Geographical diversity of the 601 polygons was also rather low, as testified by the mean value of evenness (0.162, Figure 3). This means that polygons were generally complex, but the inclusions of different landscapes were not spatially relevant.

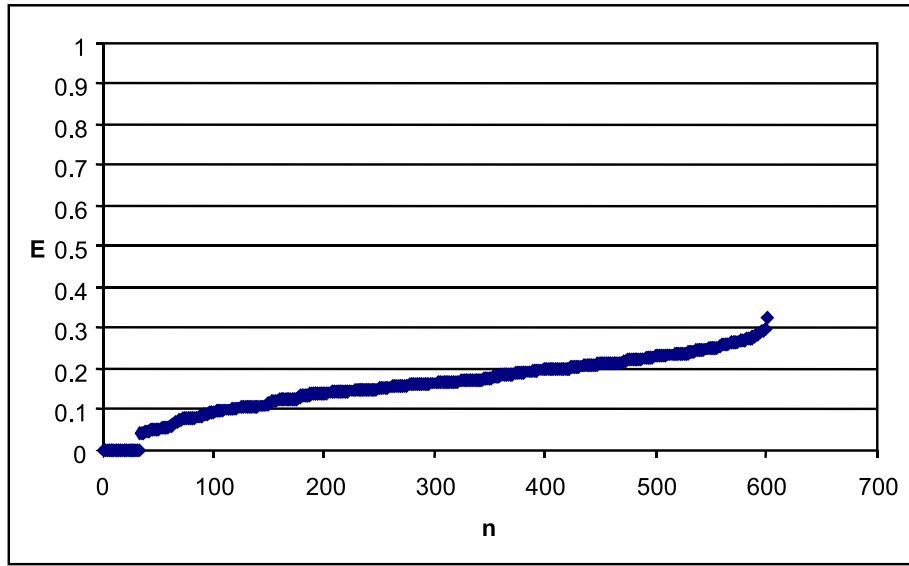


Figure 3. Geographical diversity of polygons. $pi = LE/\text{polygon (km}^2/\text{km}^2)$; E mean = 0.162.

Polygons showed a higher degree of diversity in terms of soils, and the mean value of evenness reached 0.271. This was due to the interaction between geographical diversity of polygons and pedological diversity of landscapes. The evenness index of soils expresses the pedological purity inside each polygon, as is detailed in Figure 4.

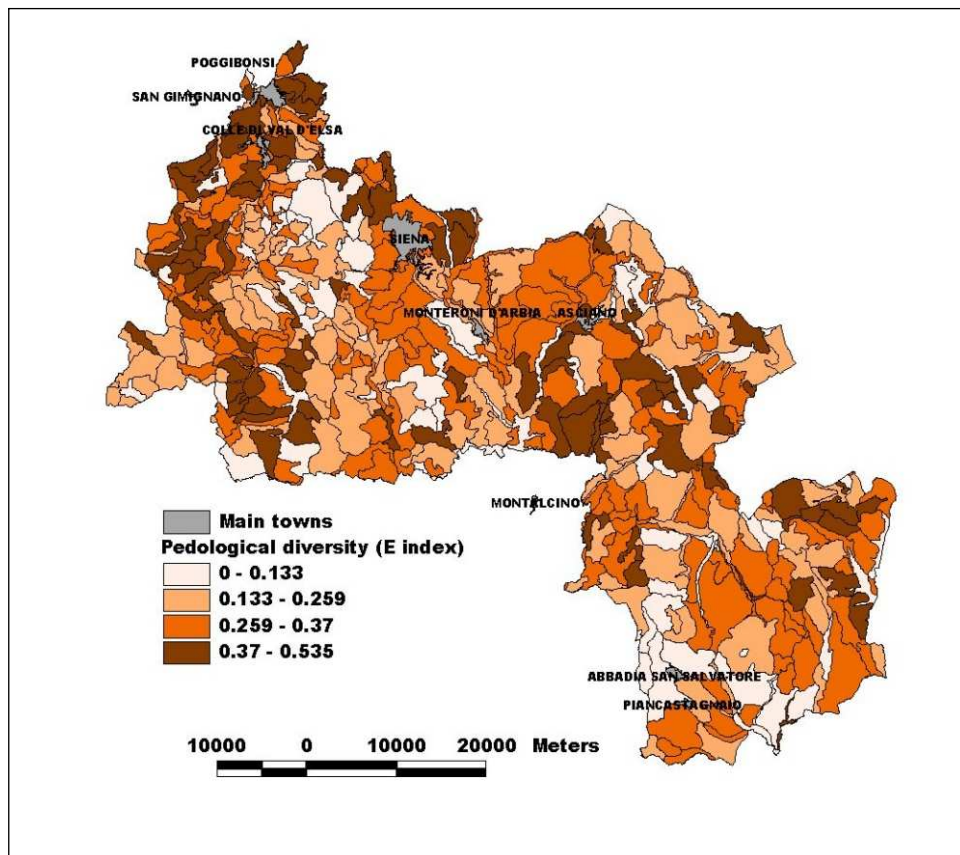


Figure 4. Pedological purity of each polygon. The higher the evenness index the higher the soil diversity.

In Figure 5 is reported the land suitability map for olive tree cultivation. Because of the variability of classes inside each polygon, rather than reporting the dominant class of each polygon, the legend of the map reported different levels of probability of finding soils belonging to different classes of suitability.

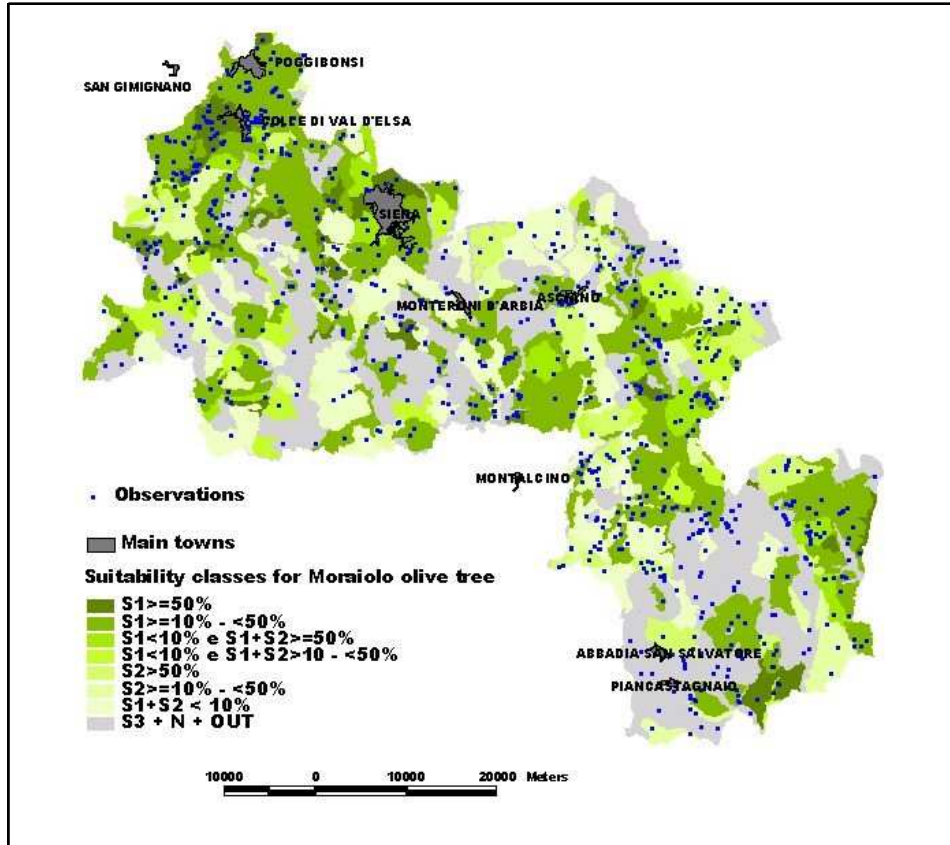


Figure 5. Land suitability map for olive tree cultivation and location of the observations.

Purity of the land suitability evaluation was more complex. We had a small group of very homogeneous polygons, but most of them showed a considerable evenness (Figure 6). In other words, most polygons were formed by soil components belonging to different land suitability classes.

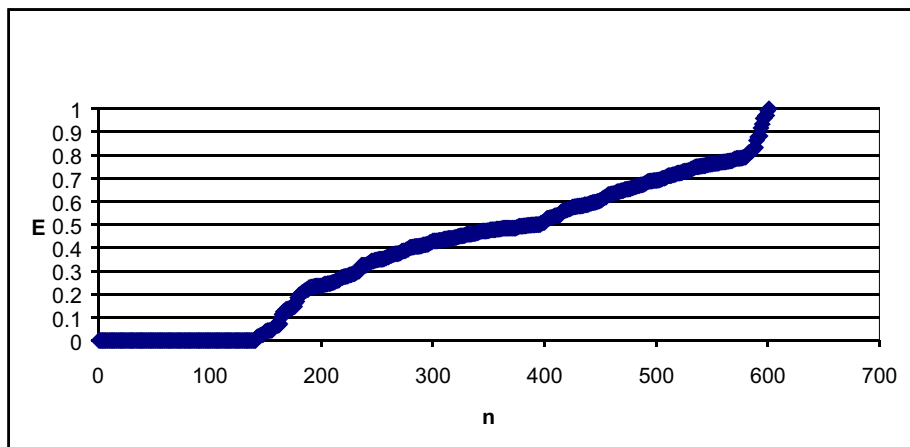


Figure 6. Purity of the land suitability. $p_i = \text{class/polygon (km}^2/\text{km}^2)$; E mean = 0.365

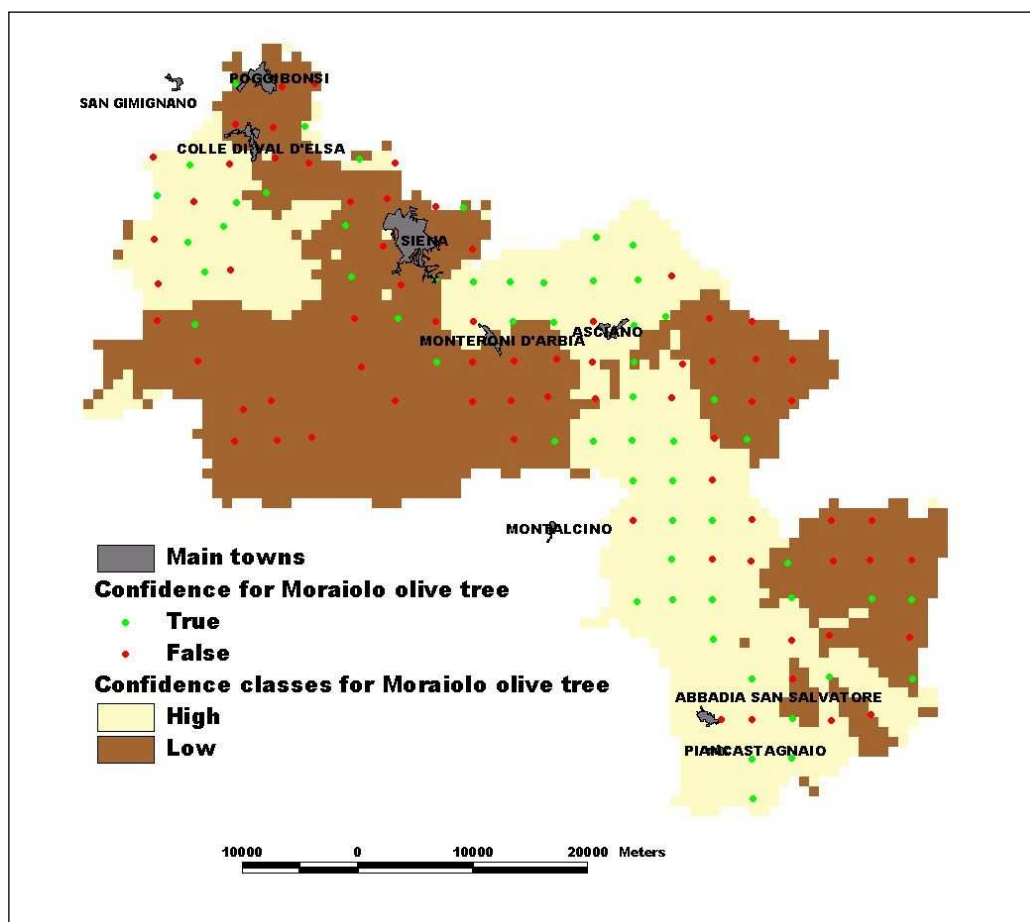


Figure 7. Confidence of the land suitability. Agreement between the land suitability evaluation obtained with the land system approach and the independent survey (two classes: true or false). Spatialisation with linear kriging.

The results of the independent survey highlighted that some 70 of the 127 observations had a land suitability evaluation for olive tree cultivation different from that predicted with the land system methodology. The computed semivariogram did not show any structured spatial variability of the kriging indicator.

However, a linear function was chosen to spatialise the punctual information. Figure 7 shows the zones of the suitability map that resulted most prone to uncertainty; they corresponded in many cases to areas with high landscape and pedological diversity.

When we considered the four possible classes of difference between the land system approach and the independent survey, the results indicated that most of the false cases were related to one or two classes of difference.

This is testified by the RMSE (a little more than one class of difference between predicted and observed) and the IoA with almost 70% of confidence. Also in this case, the computed semivariogram did not show any structured spatial variability of the indicator kriging and a linear model was chosen to spatialise the punctual information (Figure 8).

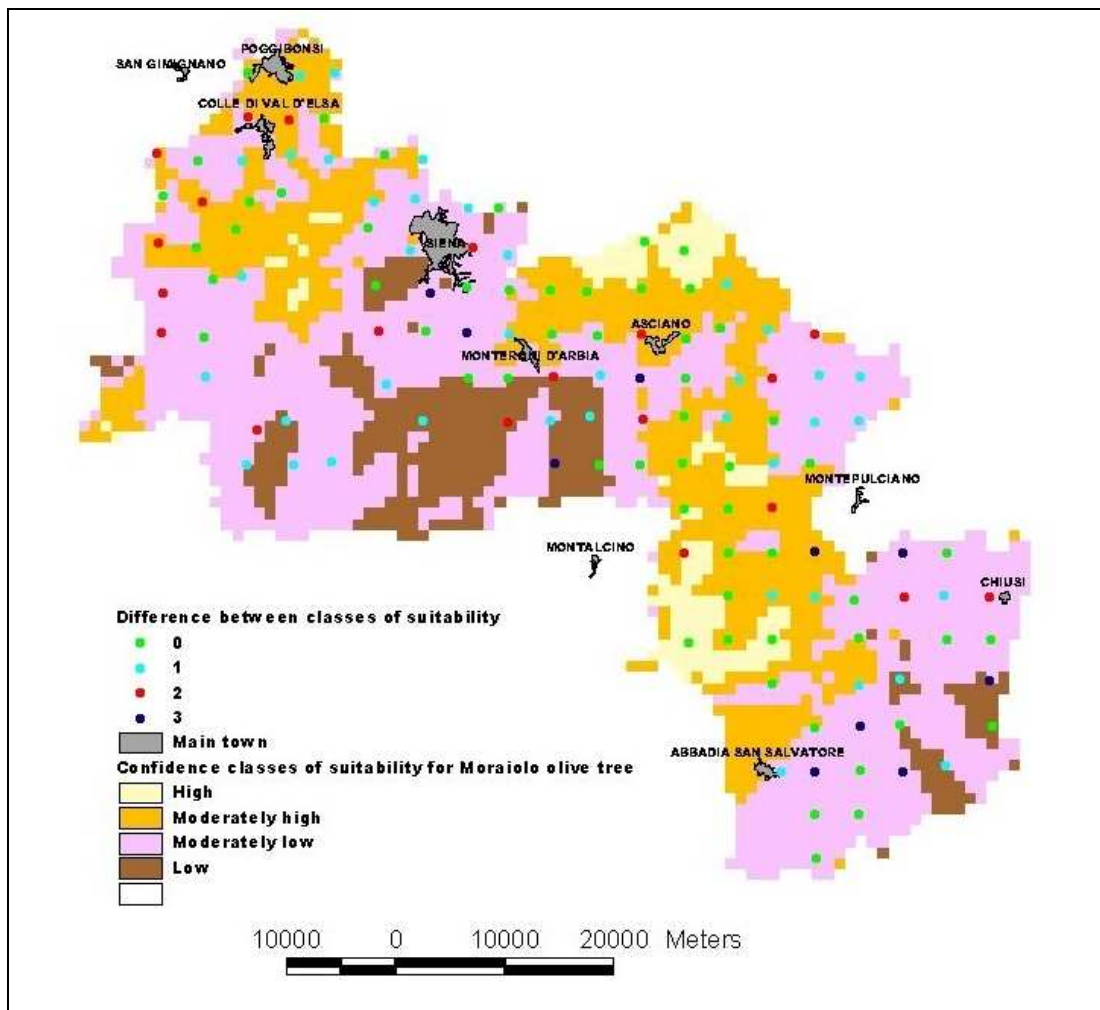


Figure 8. Confidence of the land suitability. Four classes of possible difference between the land system approach and the independent survey (high = no difference, moderately high = 1 class of difference, moderately low = 2 classes of difference, low = 3 classes of difference); RMSE=1.31, IoA=0.67.

Conclusions

This work has attempted to apply algorithms coming from the Theory of Information, geostatistic and non-parametric statistics, to make the uncertainty provided by soil and land suitability maps more explicit.

The fundamental role played by the Geographic Information System in storing and elaborating the data on soils and landscape, as well as in georeferencing the uncertainty must be stressed. This was made possible because all information, not only about soil, but also about landscape, was adequately codified for the specific scale of investigation. In other words, a proper degree of generalisation was based on appropriate sources of information.

The study area, which can be considered representative of the Mediterranean region, showed high pedodiversity and landscape diversity at the semi-detailed scale, but the

relationship between soil and landscape was on average rather low. This is another element to demonstrate the difficulty in the study of these soils.

As a final remark we can conclude that a new perspective in soil cartography can be pointed out: a comprehensive and appropriate description and codification of the landscape at different scales, coupled with an evaluation of soil diversity inside each polygon.

References

- Burrough P.A. (1986). Principles of Geographical Information Systems for Land Resources assessment. New York: Oxford University Press.
- Costantini E. A. C., Gardin L., Pagliai M. (1999). Advances in soil survey, monitoring and applications in Italy. In: Soil Resources of Europe (Eds. Bullock, Jones & Montanarella). JRC, Ispra (VA), Italy, p.103-109.
- Costantini E.A.C., Sulli L. (2000). Land evaluation in areas with high environmental sensitivity and qualitative value of the crops: the viticulture and olive-growing zoning of the Siena province. *Boll. S.I.S.S.*, 49 (1-2), p. 219-234.
- FAO (1979). Soil survey investigation for irrigation. FAO soils bulletin 42, Rome, pp. 188.
- Hudson B.D. (1992). The soil survey as paradigm-based science. *Soil Sc. Soc. Am. J.* 56, 836-841.
- Ibañez J.J., De-Alba S., Bermudez F.F., Garcia-Alvarez A. (1995). Pedodiversity: concepts and measures. *Catena*, 24, p. 215-232.
- Ibañez J.J., De-Alba S., Lobo A., Zucarello V. (1998). Pedodiversity and global soil patterns at coarse scales (with Discussion). *Catena*, 83, p. 171-214.
- Soil Survey Division Staff (1993). Soil Survey Manual. USDA Handbook n. 18, Washington D.C., USA, pp.437.
- Soil Survey Staff (1999). Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd ed. USDA-NRCS Agric. Handb. 436. U.S. Gov. Print. Office, Washington, DC.
- Toscana. Dip. Agricoltura e Foreste, (1992). I sistemi territoriali della Comunità montana Alto Mugello Mugello Val di Sieve: studio per una caratterizzazione fisica dell'ambiente mugellano (Progetto sistemi territoriali). Giunta Regionale Toscana, Firenze, pp.198.
- Van Wambeke A. and Forbes T. (1986). Guidelines for using Soil Taxonomy in the names of soil mapping units. SMSS Technical Monograph N° 10, USDA, Washington D.C., USA